CHAPTER 5

RADIOLOGICAL IMPACT

A. Introduction

Limited amounts of radioactivity are ultimately released to the environment in liquid and airborne effluents during the routine operation of nuclear power plants. Three nuclear power plants whose releases can produce an environmental impact in Maryland are the Three Mile Island Nuclear Station (TMINS), the Peach Bottom Atomic Power Station (PBAPS), and the Calvert Cliffs Nuclear Power Plant (CCNPP). The Peach Bottom and Three Mile Island plants are located on the Susquehanna River in Pennsylvania; Calvert Cliffs is located on the Chesapeake Bay in Maryland.

Nuclear power plants operating in the United States are licensed and regulated by the U.S. Nuclear Regulatory Commission (USNRC). Conditions imposed in each plant's operating license permit the routine discharge of low levels of radioactivity to the environment. Aqueous and atmospheric releases are restricted by regulations contained in 10 CFR 50 Appendix I, which are designed to keep radiation doses "as low as reasonably achievable." Annual total body doses to a hypothetical maximally exposed individual cannot exceed 3 millirems (mrem) per reactor for the aqueous pathway and 5 mrem per reactor for the atmospheric pathway (Table 5-1).

Exposure pathways for radioactivity introduced into the environment that may affect humans are illustrated in Figure 5-1. Aqueous pathway doses are received through ingestion of radioactivity contained in water and seafood, and exposure to contaminated water and sediments. Atmospheric pathway doses may result from inhalation of and direct exposure to radioactive gaseous and airborne particulate matter in a passing plume. Atmospheric pathway doses may also be received through the ingestion of radionuclides deposited on or taken up by terrestrial vegetation and animals.

This chapter presents an assessment of the impact on Maryland's health and environment of radioactivity released from the Peach Bottom and Calvert Cliffs plants. This assessment is based on results of environmental monitoring and research conducted by PPER, the individual utilities, and the Maryland Department of the Environment (MDE). It includes the quantities of radioactive effluents released by each plant, radionuclide concentrations detected and their distribution in the environment, and calculated radiation dose commitments to humans. It compares these quantities with natural background doses, plant operating license restrictions, and environmental radionuclide concentrations detected in previous years.

Radioactivity released during routine operations of the Three Mile Island plant was not detected in Maryland in 1987-1988, or previously (GPUN 1989; PPRP 1988). No impact to Maryland's public health or environment from the Three Mile Island plant is indicated.

Table 5-1
NRC Guidelines: limiting conditions of operation of light-water cooled nuclear power reactors to keep radioactivity in effluents to unrestricted areas as low as is reasonably achievable

Type of Dose	Design objectives[a]	Point of Dose evaluation
Liquid Effluents		
Dose to whole body	3 mrem/yr per unit	Location of highest offsite dose[b]
Dose to any organ	10 mrem/yr per unit	Location of highest offsite dose[b]
Gaseous Effluents[c]		
Gamma dose in air	10 mrad/yr per unit	Location of highest offsite dose[d]
Beta dose in air	20 mrad/yr per unit	Location of highest offsite dose[d]
Dose to total body	5 mrem/yr per unit	Location of highest offsite dose[b]
Dose to skin	15 mrem/yr per unit	Location of highest offsite dose[b]
Atmospheric Radioiodines and Particulates[e]		
Dose to any organ	15 mrem/yr per unit	Location of highest offsite dose[f]

Source: 10 CFR 50, Appendix 1

(a) Evaluated for a maximally exposed individual.

(b) Evaluated at a location that is anticipated to be occupied during the plant lifetime, or with respect to such potential land and water usage and food pathways as could actually exist during the term of plant operation.

(c) Calculated for noble gases only.

(d) Evaluated at a location that could be occupied during the term of plant operation.

(e) Doses due to Carbon-14 and tritium intake from terrestrial food chains are included.

(f) Evaluated at a location where an exposure pathway and dose receptor actually exist at the time of licensing. However, if the applicant determines design objectives with respect to radioiodine on the basis of existing conditions and if potential changes in land and water usage and food pathways could result in exposures in excess of the values given above, the applicant must provide reasonable assurance that a monitoring program will be performed to determine: (1) the quantities of radioiodine actually released to the atmosphere and deposited relative to those estimated in the determination of design objectives; (2) whether changes in land and water usage and food pathways which would result in individual exposures greater than originally estimated have occurred; and (3) the content of radioiodine in foods involved in the changes, if they occur.

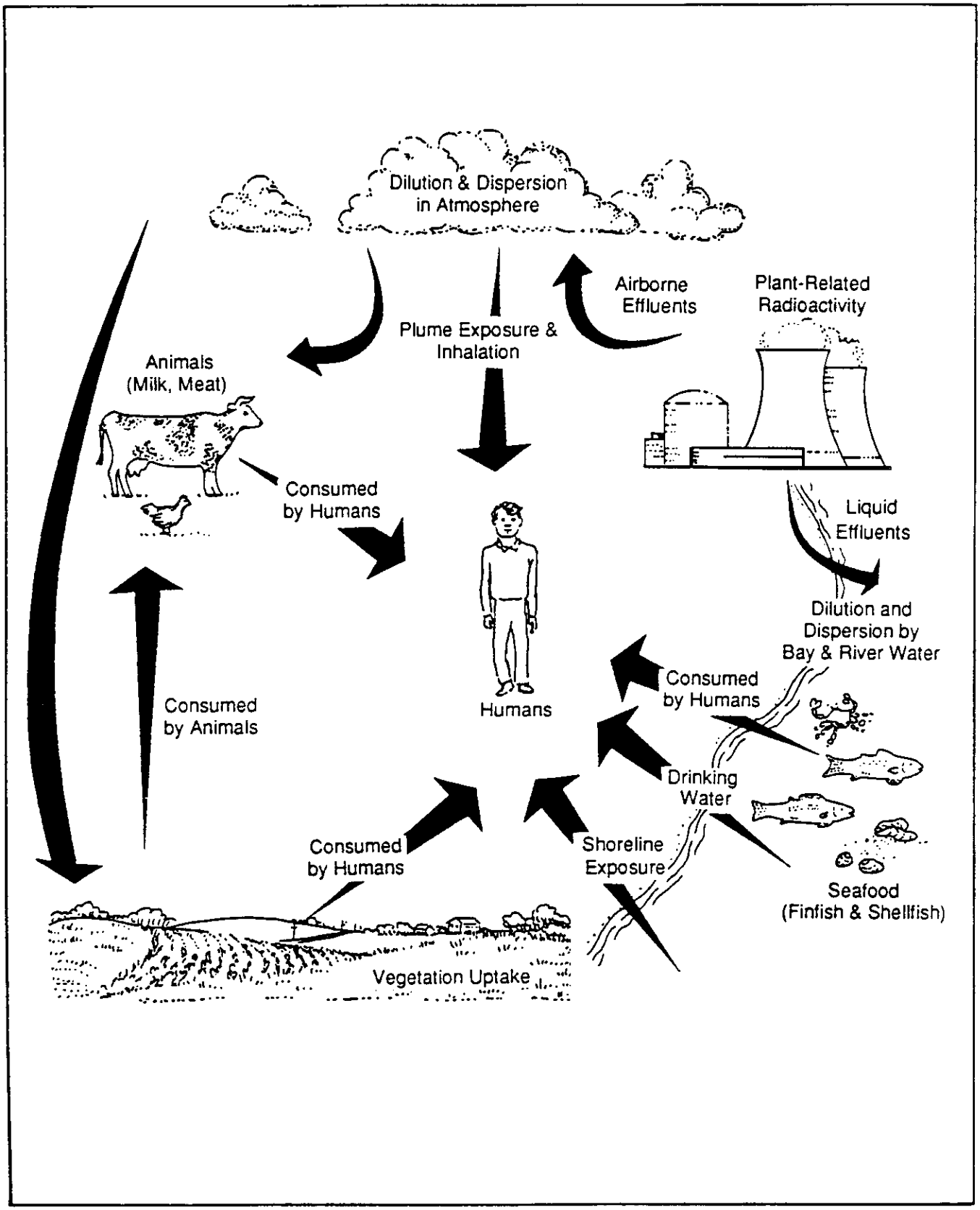

Figure 5-1. Exposure pathways for radioactivity introduced into the environment which may contribute to a human radiation dose

Source: GPUN 1989; Eisenbud 1987

B. Calvert Cliffs Nuclear Power Plant

The Calvert Cliffs plant, owned and operated by Baltimore Gas & Electric Company (BG&E), is located on the western shoreline of the Chesapeake Bay in Calvert County, Maryland. Each of its two units is a pressurized water reactor with a maximum dependable capacity of 860 MW per reactor. Unit 1 was placed into commercial service on 8 May 1975 and has produced 75,608,827 MWH gross of electrical energy from 1975-1988. Unit 2 was placed into commercial service on 1 April 1977 and has produced 70,772,632 MWH gross of electrical energy from 1977-1988. By the end of 1988, Units 1 and 2 had achieved cumulative unit capacity factors of 73.1 percent and 79.5 percent, respectively (BG&E 1989a).

1989 Shutdown

On 5 May 1989, BG&E discovered several leaks in CCNPP's Unit 2 pressurizer. Unit 2 was shut down for refueling. BG&E then shut down Unit 1 to see if any such cracks were present in its pressurizer. Although none were found, Unit 1 remained shut down while BG&E investigated the cracking in Unit 2. USNRC conducted a Special Teams Inspection and reviewed BG&E's implemented and planned corrective actions to determine if performance had been raised to a level that would allow them to start up and operate the plant safely. Following numerous subsequent inspections and reviews, USNRC concluded in April 1990 that Unit 1 was ready for restart. Unit 1 was returned to service in September 1990; Unit 2 is expected to resume operation in 1991.

Releases of Radioactivity to the Environment

Calvert Cliffs releases gaseous and liquid radioactive effluents into the atmosphere and the Chesapeake Bay. Quantities of radioactivity contained in these effluents are dependent upon plant operating conditions and power levels, nuclear fuel conditions, and the efficiency of liquid and gas processing systems. To date, atmospheric and liquid releases of radioactivity to the environment by Calvert Cliffs have been well within regulatory limits.

- Atmospheric

Radionuclides released to the atmosphere by the plant in 1987 and 1988 as reported by BG&E are presented in Table 5-2. Noble gas radionuclides of xenon (Xe-131m, Xe-133, Xe-135) and krypton (Kr-85, Kr-85m) accounted for virtually all of the radioactivity released to the atmosphere. These radionuclides are chemically inert and are of little environmental concern. They are readily dispersed in the atmosphere upon release and have short half-lives, permitting their rapid decay to stable forms.

Iodine-131 (I-131) and cesium-137 (Cs-137) were the other notable radionuclides contained in the plant's atmospheric releases. To date, atmospheric dispersion of the low quantities of I-131 released and I-131's short half-life have effectively minimized the potential for environmental impact. Similarly, atmospheric dispersion of the low quantities of Cs-137 released has resulted in an indiscernible

Table 5-2
Total quantities (Curies) of radionuclides released to the atmosphere by CCNPP: 1987-1988

Radionuclide	1987	1988
Tritium:	**0.55580**	**12.186**
Noble Gases:		
Kr-85	10.72000	67.52000
Kr-85m	6.22600	44.63300
Kr-87	0.53820	9.08100
Kr-88	0.00715	4.45990
Xe-131m	34.76000	32.00800
Xe-133	1,810.80000	5,844.60000
Xe-133m	18.30800	47.61000
Xe-135	87.53000	373.03000
Xe-135m	0.00026	0.00326
Ar-41	0.02788	0.06082
Total:	**1,968.91749**	**6,423.00598**
Iodines:		
I-131	0.09170	0.12454
I-133	0.07190	0.11710
I-135	0.00000	0.00009
Total:	**0.16360**	**0.24173**
Particulates:		
Co-57	0.00000	<0.00001
Co-58	0.00004	0.00002
Co-60	<0.00001	<0.00001
Sr-89	0.00004	0.00000
Sr-90	<0.00001	0.00000
Cd-109	0.00002	0.00000
Te-132	0.00000	<0.00001
Cs-134	<0.00001	0.00002
Cs-137	0.00004	0.01168
Ce-141	<0.00001	0.00000
Ce-144	0.00000	0.00001
Total:	**0.00018**	**0.01176**
Total curies:	**1,969.64**	**6,435.46**

Source: BG&E 1988b, 1989c

increment, if any, when compared to environmental Cs-137 concentrations attributable to weapons test fallout.

- Liquid

Radionuclides released to the Chesapeake Bay by Calvert Cliffs in 1987 and 1988 as reported by BG&E are presented in Table 5-3. Cobalt-58 (Co-58), cobalt-60 (Co-60), zinc-65 (Zn-65), and silver-110m (Ag-110m) were the principal environmentally significant radionuclides in aqueous releases. These radionuclides are readily accumulated by Bay biota, such as oysters and crabs, and become associated with particulate material and Bay sediments (McLean *et al.* 1982; Domotor and McLean 1987, 1988, 1990a). Through food chain transport, these radionuclides may ultimately contribute to a radiation dose to humans. The aqueous pathway is therefore considered as having the greatest potential for producing an environmental impact.

With the exception of Co-58, quantities of environmentally significant radionuclides released by the plant and subsequently detected in biota and sediments were very small, as in previous years (Table 5-4). Release quantities of Co-58 for 1987 were significantly greater than for 1988 or the 1985-1986 reporting period, resulting in the more frequent detection of Co-58 in Chesapeake Bay media collected during 1987.

In addition to releases via the primary cooling water outfall (001), low levels of radioactivity may be discharged from the Calvert Cliffs plant via a stormwater outfall (002) that terminates on a beach to the northeast of the plant site. Low levels of radionuclides are routinely detected in silt samples collected from the 002 outfall pool.

Environmental Monitoring Programs

BG&E, MDE, and PPER conduct environmental surveillance programs in the vicinity of Calvert Cliffs to assess radiological impact attributable to plant operation. BG&E's program focuses primarily on atmospheric and terrestrial impacts, but also includes aquatic monitoring; it is structured to conform to USNRC operating license requirements. MDE performs assurance monitoring to provide an independent confirmation of BG&E's program. PPER's monitoring program focuses on radiological impact within the Chesapeake Bay ecosystem. It is designed to provide information concerning environmental and health-related impacts of radioactivity released via the aqueous pathway. Detailed descriptions of individual environmental surveillance programs may be found elsewhere (BG&E 1989b; Domotor and McLean 1990a).

Atmospheric and Terrestrial Radionuclide Distributions

- Atmospheric

No radioactivity attributable to Calvert Cliffs was detected in air particulate, air iodine, or precipitation samples collected weekly from plant site and distant

Table 5-3
Total quantities (Curies) of radionuclides released to the Chesapeake Bay by CCNPP via the aqueous pathway: 1987-1988

Radionuclide	1987	1988
Tritium:	**737.60**	**347.90**
Dissolved Noble Gases:		
Xe-131m	0.00098	0.00000
Xe-133	1.28520	0.00000
Xe-133m	0.01143	0.00000
Xe-135	0.02558	0.00000
Xe-135m	0.03656	0.00000
Kr-85m	0.00011	0.00000
Total:	**1.35986**	**0.00000**
Iodines:		
I-131	0.49920	0.27930
I-132	0.00299	0.00171
I-133	0.13489	0.02538
I-134	0.00006	0.00000
I-135	0.02767	0.00067
Total:	**0.66481**	**0.30706**
Particulates:		
Na-24	0.00966	0.00123
Cr-51	0.12382	0.08539
Mn-54	0.01777	0.00882
Fe-59	0.00221	0.00022
Co-57	0.00019	0.00026
Co-58	1.65730	0.47848
Co-60	0.16512	0.03313
Sr-89	0.00366	0.00344
Sr-90	0.00157	0.00045
Sr-91	0.00019	0.00000
Zr-95	0.04863	0.01656
Nb-95	0.09845	0.03169
Nb-97	0.00115	0.00710
Mo-99	0.00206	0.00096
Te-99m	0.00420	0.00363
Tc-99m	0.00000	0.00004
Ru-103	0.00618	0.00301
Ru-106	0.00038	0.00000
Ag-108m	0.00000	0.00002
Cd-109	0.00079	0.01140

Table 5-3 (Continued)
Total quantities (Curies) of radionuclides released to the Chesapeake Bay by CCNPP via the aqueous pathway: 1987-1988

Radionuclide	1987	1988
Particulates (continued):		
Ag-110m	0.06880	0.06874
Sn-113	0.00770	0.00217
Sb-122	0.00035	0.00000
Sb-124	0.01343	0.02047
Sb-125	0.31000	0.16960
Te-129	0.00000	0.00004
Te-132	0.00088	0.00067
Cs-134	0.80020	0.44777
Cs-136	0.00388	0.00462
Cs-137	0.91250	0.93080
Ba-140	0.00010	0.00002
La-140	0.00015	0.00033
La-142	0.00029	0.00166
Ce-141	0.00008	0.00057
Ce-144	0.00000	0.00221
W-187	0.00015	0.00057
Hg-203	0.00000	0.00005
Total:	**4.26184**	**2.33612**
Total curies:	**743.89**	**350.54**

Source: BG&E 1988b, 1989c

Table 5-4
Annual aqueous release quantities (Curies) from CCNPP of radionuclides that have been detected in environmental media collected from the Chesapeake Bay: 1979-1988

Release Year	Radionuclide				
	Tritium	Cobalt-58	Cobalt-60	Zinc-65	Silver-110m
1979	514	3.81	0.33	< DL*	0.10
1980	491	2.00	0.44	0.02	0.03
1981	1001	1.30	0.21	< DL	0.02
1982	435	1.50	0.19	< DL	0.22
1983	756	0.61	0.08	< DL	0.08
1984	787	0.57	0.10	< DL	0.10
1985	483	0.91	0.10	< DL	0.17
1986	735	0.47	0.12	0.0001	0.06
1987	738	1.66	0.16	< DL	0.07
1988	138	0.48	0.03	< DL	0.07

Source: PPRP 1988; BG&E 1988b, 1989c.
* Below detection limit.

locations during 1987. Gross alpha and beta concentrations were characteristic of background levels measured in previous years; concentrations at plant site and distant locations were similar (DHMH 1987; BG&E 1988a).

BG&E detected I-131 in air iodine samples from two air monitoring stations -- one at the plant site and another 1.6 miles southeast of the plant -- during the week of 4 January 1988. The concentrations detected were very low with large counting errors, and were close to the minimum detectable values for samples collected at all BG&E locations. No I-131 was detected in air iodine samples collected during the same period by MDE at an air monitoring station close to BG&E's plant site monitoring location. Although no environmental or health-related impact is indicated, the detection of I-131 is significant in that I-131 attributable to plant operation has never been previously detected. No other plant-related radioactivity was detected in air particulate or precipitation samples collected from the Calvert Cliffs vicinity during 1988 (DHMH 1988; BG&E 1989b).

Low concentrations of Cs-137 originating from fallout of past atmospheric weapons tests were sporadically detected at all locations. Concentrations of fallout-related Cs-137 have continued to decline since their peak in 1980-1981, which was associated with the Chinese weapons test of 15 October 1980. Naturally occurring beryllium-7 (Be-7) was routinely detected in air particulate samples from all locations throughout the two-year period.

External radiation, as measured by thermoluminescence dosimetry (TLD) at 23 locations surrounding the plant, indicated that atmospheric releases of radioactivity during 1987-1988 did not contribute to off-site radiation levels (BG&E 1988a, 1989b). No plant-related contribution to the measured exposure rate was discernible.

- Terrestrial

Low concentrations of Cs-137 were sporadically detected in crop and vegetation samples collected from on-site and distant farms during 1987-1988. Concentrations detected at all locations were comparable to levels observed in previous years; no plant-related increment is discernible. Manganese-54 (Mn-54) was the only plant-related radionuclide detected (on a single occasion) in a crop sample in October 1987. Co-58 and Co-60, detected in previous years, were not detected.

CCNPP-related radionuclides were also detected in silt samples collected from the pool into which stormwater outfall 002 terminates. Co-58, Co-60, Ag-110m, antimony-125 (Sb-125), Cs-134, and Cs-137 were consistently detected in spring, summer, and fall collections each year. Concentrations of all radionuclides were highest in spring, as in the previous reporting period. Plant-related Mn-54, zirconium-95 (Zr-95), ruthenium-106 (Ru-106), and cerium-144 (Ce-144) were also detected in spring 1987 (Domotor and McLean 1990a).

Radioactivity released into the 002 outfall was first detected in 1979 (McLean *et al.* 1982). The source of radioactivity was subsequently determined to be the diesel oil

interceptor. Downwash of stack releases during rainfall, mixed with the stormwater inventory, may add to the increment of radioactivity detected at this outfall. This is supported by the higher concentrations of radionuclides consistently detected in the spring, which tends to see more precipitation and run-off than other seasons. The range of concentrations detected during 1987-1988 is comparable to levels detected in previous years and does not currently represent a significant environmental impact.

Aquatic Radionuclide Distributions

Co-58, Co-60, Ag-110m, and Zn-65 were the environmentally significant radionuclides attributable solely to Calvert Cliffs releases detected in Chesapeake Bay media. Co-58 and Ag-110m were the plant-related radionuclides most frequently detected in biota. With the exception of Zn-65, they were also frequently detected in Bay sediments (BG&E 1988a, 1989b; Domotor and McLean 1990a). Maximum concentrations of plant-related radionuclides detected in Chesapeake Bay media during 1987-1988 are presented in Table 5-5.

Radionuclides originating from natural sources and atmospheric nuclear weapons tests were also detected. Naturally occurring potassium-40 (K-40) and radionuclides of the thorium and uranium decay series were detected in most biota and all sediment samples. Be-7 was also frequently detected, primarily in sediments. Low concentrations of Cs-137 were detected in virtually all Bay sediments, and were frequently detected in a variety of Bay biota samples. While Calvert Cliffs releases small quantities of Cs-137 as liquid effluent, a comparison of the range of concentrations detected at the plant site with those at more distant locations indicates that weapons test fallout is the principal source.

- Bay Water

The almost daily release of tritium in Calvert Cliffs' liquid effluent may occasionally produce concentrations in local Bay water that exceed levels attributable to weapons test fallout. Rapid dilution and dispersion within Bay water reduce these concentrations to ambient levels in a short time. Thus, plant-related tritium may only be discernible if water sample collection occurs soon after tritium release. Although tritium concentrations attributable to releases were occasionally detected during previous years, no plant-related increment of tritium is evident in the current reporting period. Tritium was occasionally detected by BG&E and MDE at fallout-attributable levels (less than 500 picocuries per liter, pCi/l) during 1987-1988. Because tritium is not bioaccumulated, and release quantities have remained relatively low, no adverse environmental impact is indicated.

- Biota

Oysters are ideal indicators of environmental radionuclide concentrations because they are non-mobile and readily concentrate metals, including radionuclides. They are commercially harvested in the Calvert Cliffs region, and have the greatest potential for providing a human radiation dose through seafood

Table 5-5
Maximum concentrations of radionuclides attributed to the Calvert Cliffs Nuclear Power Plant in environmental samples collected from the Chesapeake Bay: 1987-1988

			Radionuclide Concentration (pCi/wet kg)*			
Sample Type	Collection Location	Year	Silver-110m	Cobalt-58	Cobalt-60	Zinc-65
Edible Finfish Flesh	Offshore	1987	<23	<19	<20	<41
		1988	<16	<15	<15	<30
Edible Finfish Gut		1987	<145	<366	<106	<246
		1988	<95	<110	<71	<163
Forage Finfish (Whole)	Plant Site	1987	4+-3	11+-4	<12	<23
		1988	<9	<56	<55	<112
	Farfield	1987	<17	<16	<14	<29
		1988	<63	<52	<52	<109
Oyster Meat	Plant Site	1987	154+-7	29+-4	<12	10+-4
		1988	100+-7	35+-16	<10	<24
	Farfield	1987	<16	<12	<12	<25
		1988	<19	<16	<16	<35
Blue Crab Meat	Plant Site	1987	4+-2	<14	<14	<28
		1988	25+-11	<8	<9	<17
	Farfield	1987	9+-9	<23	<20	<41
		1988	17+-10	<10	<9	<19
Blue Crab Shell	Plant Site	1987	<43	5+-21	<37	<76
		1988	74+-26	<25	<18	<36
	Farfield	1987	15+-18	<59	<51	<104
		1988	<105	22+-33	<80	<167
Grass Shrimp (Whole)	Plant Site	1987	9+-17	<50	<45	<50
		1988	56+-11	7+-6	<51	<101
	Farfield	1987	<144	<128	<102	<212
		1988	<25	<23	<27	<36

Table 5-5 (Continued)
Maximum concentrations of radionuclides attributed to the Calvert Cliffs Nuclear Power Plant in environmental samples collected from the Chesapeake Bay: 1987-1988

			Radionuclide Concentration (pCi/wet kg)*			
Sample Type	Collection Location	Year	Silver-110m	Cobalt-58	Cobalt-60	Zinc-65
Epifaunal Organisms	Plant Site	1987	<230	756+-65	163+-97	<297
		1988	84+-40	700+-577	364+-337	<701
	Rocky Point	1987	11+-49	357+-78	70+-56	<213
		1988	<140	168+-140	19+-21	<204
	Kenwood Beach	1987	<278	91+-97	<194	<463
		1988	<183	<225	<142	<318
Macro-algae	Plant Site	1987	7+-5	26+-11	<14	<25
		1988	<16	32+-14	<15	<30
	Farfield	1987	<26	<21	<17	<39
		1988	<15	<15	<13	<28
Bay Sediment (Silt/Clay)		1987	140+-13	106+-16	86+-10	<96
		1988	18+-14	31+-16	90+-30	<86
Bay Sediment (Sand)		1987	8+-4	279+-17	38+-5	<49
		1988	<15	15+-18	77+-8	<24

Source: Domotor and McLean 1990a

* Bluecrab shell and Bay sediment radionuclide concentrations in pCi/dry kg units; epifaunal organisms in pCi/ash kg units.

consumption. Ag-110m continues to be the principal plant-related radionuclide accumulated by oysters. It was consistently detected in oysters located on natural bars (bar oysters) and in oysters immersed quarterly in trays (tray oysters) located in the vicinity of the plant's liquid effluent discharge throughout 1987 and 1988 (BG&E 1988a, 1989b; Domotor and McLean 1990a). Co-58 was also frequently detected in bar and tray oysters in both years; Zn-65 was only occasionally detected in bar oysters in 1987.

Bar and tray oysters have consistently contained Ag-110m and sporadically contained low concentrations of other plant-related radionuclides (i.e., Co-58, Co-60, and Zn-65) since they were first monitored in 1978 (McLean *et al.* 1982; Domotor and McLean 1987, 1988, 1990a). Monitoring of bar oysters has shown that there is no long-term accumulation of radioactivity in oysters collected from the plant vicinity. Monitoring of tray oysters has shown that radionuclide concentrations are correlated with release quantities and with environmental conditions (e.g., water temperature) over the season of exposure. The tray oyster monitoring program has also shown that, while oysters can accumulate radionuclides, they can also eliminate large quantities of them rapidly if the source of radioactivity is eliminated. A detailed discussion of the tray oyster program, including statistical analysis and modeling of Ag-110m concentrations in oysters, can be found elsewhere (Rose *et al.* 1988; Rose *et al.* 1989).

Forage finfish contained low concentrations of Calvert Cliffs radionuclides on several occasions during 1987-1988. Low concentrations of Co-58 and Ag-110m were detected in menhaden and silversides (forage finfish that are prey for edible predator finfish) collected from the plant site in 1987. While low concentrations of Co-58, Co-60, and Ag-110m have been sporadically detected in nearfield forage finfish since first being monitored in 1978, plant-related radionuclides have never been detected in any edible finfish.

As was observed in previous reporting periods, low concentrations of Ag-110m were detected in blue crab meat and shell from both plant site and distant locations. Concentrations were similar at both locations, indicating that the crabs moved from the plant vicinity to more distant locations after uptake of Ag-110m, transporting radioactivity away from the immediate plant vicinity. Co-58 was detected in blue crab shell from both locations in 1987; it had not been detected in the previous reporting period. Ag-110m and Co-58 were also occasionally detected in grass shrimp collected from the plant site during 1987-1988.

Co-58 was consistently detected in several species of macro-algae (which are a food source of blue crabs and grass shrimp) collected from the plant site throughout 1987 and through summer 1988; concentrations were higher than for 1985-1986. A comparison of Co-58 release quantities with Co-58 concentrations and their frequency of detection in macro-algae from 1983 to 1988 suggests that these organisms are good indicators of radiocobalt in the environment. Macro-algae collected from the plant site in 1987 also contained low concentrations of Ag-110m.

Co-58 and Co-60 were the principal radionuclides detected in epifauna (chiefly barnacles) collected from wooden panels submerged at near and distant locations. Both radionuclides were detected more frequently and at higher concentrations in epifauna from the plant site, particularly in 1987. The radiocobalt detected may have been associated with fine sediment and organic material trapped by the substrate, rather than incorporated within the organisms themselves.

- Sediments

Sediments are useful indicators of environmental radionuclide concentrations because they serve as sinks for both stable and radioactive metals. Sediments are collected quarterly by PPER from eight transects extending bayward north and south of Calvert Cliffs. Co-58, followed by Co-60 and Ag-110m, were the plant-related radionuclides frequently detected in Bay sediments. Co-58 concentrations detected in sediments during 1987 were generally higher than those detected in 1988, or in the previous reporting period. Co-58 concentrations were at their maximum in spring and summer of 1987, decreasing in fall 1987 through 1988 to ranges observed in previous years. Concentrations of Co-60 and Ag-110m were similar to levels detected in previous years (Domotor and McLean 1990a).

All three radionuclides were sporadically detected along the western shore of the Bay as far as three miles south of Calvert Cliffs, indicating that particle-bound radioactivity is transported away from the immediate plant vicinity, generally in a down-Bay direction. The transport of these sediments is facilitated by estuarine circulation, sediment scouring, resuspension, and dispersion. These hydrological and physical processes also act to reduce the potential for nearfield accumulation of plant-associated radioactivity.

Radiation Dose to Humans

Estimates of dose commitments to individuals consuming seafood were calculated using the maximum plant-related radionuclide concentrations (for Co-58, Co-60, Zn-65, and Ag-110m) detected in oysters harvested in the immediate vicinity of Calvert Cliffs. Estimated dose commitments to adults, teenagers, and children are presented in Table 5-6. The estimated maximum dose from consumption of oysters would be less than 0.05 mrem to an adult's gastrointestinal tract. The estimated maximum total body dose to an adult would be less than 0.001 mrem.

The detection of plant-related radioactivity in blue crabs is significant in that their consumption may also provide a human radiation dose. The estimated maximum dose from the consumption of seafood, incorporating dose commitments from both oysters and blue crabs, is conservatively estimated to be less than 0.06 mrem per year to an adult's gastrointestinal tract. The maximum total body dose to an adult would still be less than 0.001 mrem. Since the plant began operation, radiation doses to a hypothetical maximally exposed individual have not exceeded 0.28 mrem to the GI tract, and total body doses have been less than 0.01 mrem. These dose estimates are well below 10 CFR 50 Appendix I design limits, which restrict off-site total body doses to a maximally exposed individual to 6 mrem for the aqueous pathway.

Table 5-6
Maximum estimated dose commitments* (in mrem) for an individual consuming oysters affected by CCNPP releases

	ADULT		TEEN		CHILD	
	1987	1988	1987	1988	1987	1988
Total Body						
Co-58	0.0002	0.0003	0.0002	0.0003	0.0003	0.0003
Co-60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zn-65	0.0003	0.0000	0.0004	0.0000	0.0004	0.0000
Ag-110m	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
TOTAL:	**0.0006**	**0.0004**	**0.0007**	**0.0004**	**0.0008**	**0.0004**
Bone						
Co-58	--	--	--	--	--	--
Co-60	--	--	--	--	--	--
Zn-65	0.0002	0.0000	0.0002	0.0000	0.0002	0.0000
Ag-110m	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
TOTAL:	**0.0003**	**0.0001**	**0.0003**	**0.0001**	**0.0003**	**0.0001**
Liver						
Co-58	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Co-60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zn-65	0.0008	0.0000	0.0008	0.0000	0.0006	0.0000
Ag-110m	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
TOTAL:	**0.0010**	**0.0002**	**0.0010**	**0.0002**	**0.0008**	**0.0002**
Kidney						
Co-58	--	--	--	--	--	--
Co-60	--	--	--	--	--	--
Zn-65	0.0005	0.0000	0.0005	0.0000	0.0004	0.0000
Ag-110m	0.0002	0.0001	0.0002	0.0001	0.0002	0.0001
TOTAL:	**0.0007**	**0.0001**	**0.0007**	**0.0001**	**0.0006**	**0.0001**
GI Tract						
Co-58	0.0022	0.0026	0.0015	0.0018	0.0005	0.0006
Co-60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zn-65	0.0005	0.0000	0.0003	0.0000	0.0001	0.0000
Ag-110m	0.0465	0.0302	0.0319	0.0207	0.0113	0.0074
TOTAL:	**0.0492**	**0.0328**	**0.0337**	**0.0225**	**0.0119**	**0.0080**

* Based upon maximum radionuclide concentrations given in Table 5-6. Recommended consumption values and dose factors used in calculations are from the NRC Regulatory Guide 1.109.

Human radiation doses resulting from consumption of seafood containing plant-related radioactivity are a very small fraction of those attributable to natural sources. For context, the average total body radiation dose from natural sources (principally radon gas) is estimated to be about 300 mrem/yr. The dose attributable to nuclear power generation, the nuclear fuel cycle, and weapons test fallout combined is conservatively estimated to be less than 1 mrem/yr (Figure 5-2).

Summary

Atmospheric releases of radioactivity by the Calvert Cliffs plant produced detectable levels of I-131 and Mn-54 at trace concentrations in air and crop samples collected from the immediate plant vicinity during 1987-1988. Plant-related radionuclides released as liquid effluent to the Chesapeake Bay produced low levels of Co-58, Co-60, Ag-110m, and Zn-65 in Bay biota (including oysters, blue crabs, macro-algae, and epifauna) and sediments. Ag-110m was the principal radionuclide detected in oysters. As in previous years, plant-related Co-58, Co-60, and Ag-110m were detected in sediments as far as three miles south of the plant, indicating that net transport of plant-related radioactivity in sediment is down-Bay.

A comparison of radionuclide concentrations detected in the variety of biota (e.g., oysters, blue crab, and macro-algae) and sediments collected during 1987-1988 with levels detected since 1978 indicates that: 1) in general, the levels detected in 1987 and 1988 are similar to the range of concentrations detected over the past 10 years, and 2) although radionuclide concentrations do fluctuate seasonally and annually, no accumulation or build-up of plant-related radioactivity in biota and sediments is evident. The low quantities of radioactivity introduced into the environment by Calvert Cliffs are small increments to background radioactivity from natural sources and weapons test fallout. Atmospheric and aqueous releases, and radiation doses to humans, are well within regulatory limits. Ecological and human health impacts resulting from the operation of Calvert Cliffs are regarded as insignificant.

C. Peach Bottom Atomic Power Station

The Peach Bottom Station, jointly owned by the Philadelphia Electric Company (PECO), Public Service Gas and Electric Company, Delmarva Power and Light Company, and Atlantic Electric Company, is operated by PECO. The plant is located in Pennsylvania approximately three miles north of the Pennsylvania-Maryland border on the western shore of the Susquehanna River (Conowingo Pond). Each of its two units is a boiling water reactor with a maximum dependable capacity of 1,098 MW (Unit 1, a 40 MW high-temperature gas-cooled reactor, was decommissioned in 1975). Unit 2 was placed into commercial service in July 1974, and has produced 70,019,230 MWH gross of electrical energy as of the end of 1988. Unit 3 was placed into commercial service in December 1974 and has produced 70,611,432 MWH gross. By the end of 1988, Units 2 and 3 had achieved cumulative unit capacity factors of 50.2 percent and 53.2 percent, respectively

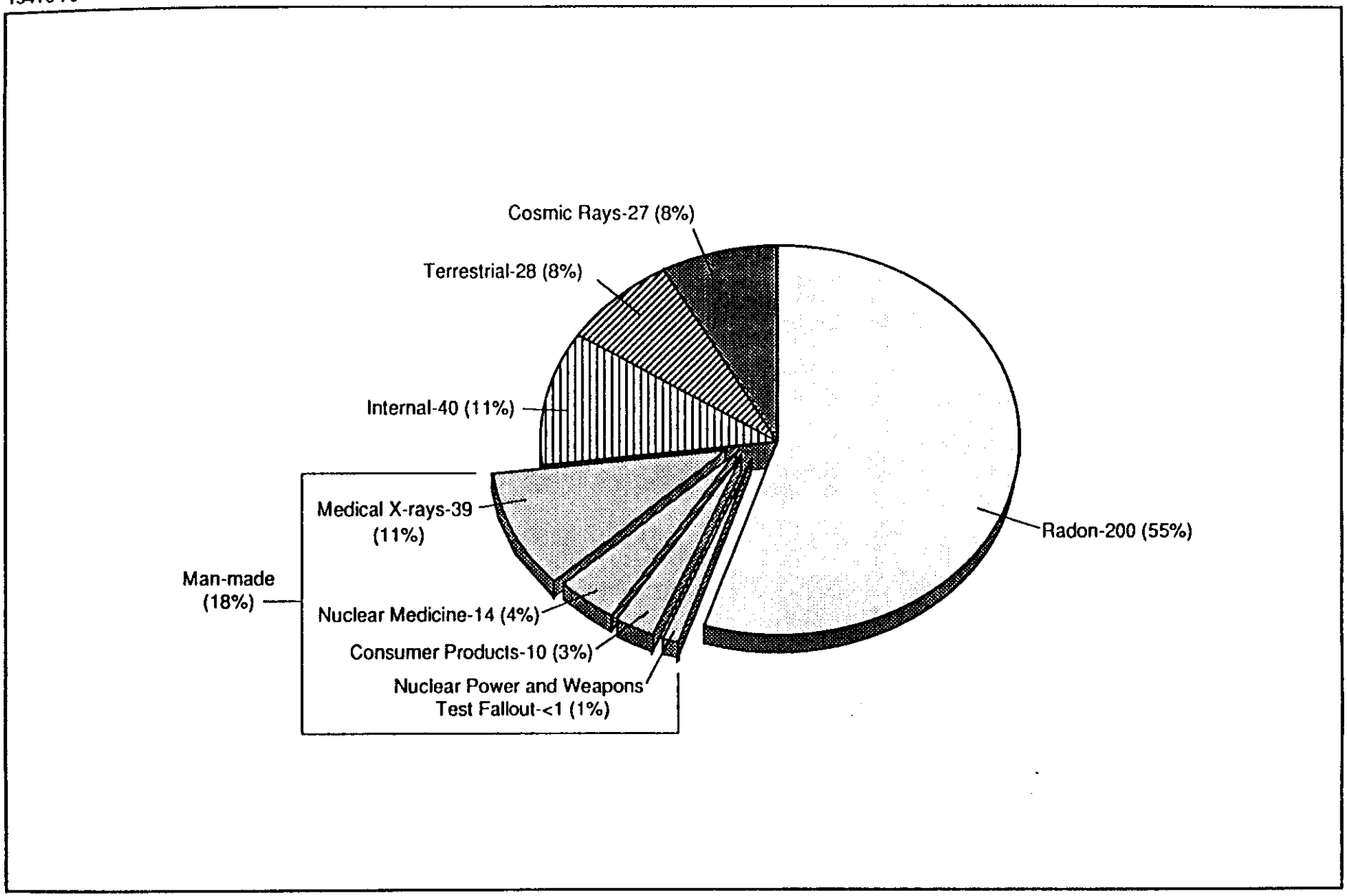

Figure 5-2. Estimated annual effective dose equivalents (mrem) for a member of the U.S. population from natural and man-made sources of radiation

Source: NCRPM 1988

(PECO 1989a). Although Units 2 and 3 are both fully operational as of this report date, they were not in operation during most of the 1987-1988 reporting period.

1987 Shutdown

On 31 March 1987, USNRC ordered the Peach Bottom Station shut down because of operator negligence. PECO made extensive management, operational, and procedural changes to improve operation of the plant. USNRC conducted an Integrated Assessment Team Inspection in February 1989 at Peach Bottom to ensure the changes had been effectively implemented. The inspection team determined that PECO's improvements were adequate to support safe operation of the plant. Unit 2 was restarted on 27 April 1989; Unit 3 was restarted on 20 November 1989.

Releases of Radioactivity to the Environment

Quantities of radioactivity released to the environment by Peach Bottom during 1987-1988 were extremely low due to the USNRC-imposed shutdown. Since the beginning of plant operation in 1974, atmospheric and liquid releases of radioactivity by PBAPS have been well within regulatory limits.

- Atmospheric

Radionuclides released to the atmosphere by the Peach Bottom plant in 1987 and 1988 as reported by PECO are presented in Table 5-7. The relatively short-lived and chemically inert noble gas radionuclides of xenon and krypton were the major components of gaseous releases in 1987. Quantities of these and the other radionuclides released in 1987 were significantly lower than in previous years due to the March 1987 shutdown. Atmospheric releases of radioactivity in 1988 (principally tritium) were extremely small; no noble gases or iodines were released.

- Liquid

Quantities of radionuclides released to the Susquehanna River (Conowingo Pond) in 1987 and 1988 as reported by PECO are presented in Table 5-8. As with the atmospheric releases, aqueous releases were extremely low due to the shutdown. Tritium comprised almost 100 percent of the liquid release inventory in each year. Present in the Susquehanna River as tritiated water, it is not bioaccumulated and is of no environmental concern.

Very low quantities of Co-58, Co-60, Zn-65, Cs-134, and Cs-137 (less than 500 millicuries, mCi) accounted for most of the remaining radioactivity released as liquid effluent. These radionuclides are environmentally significant because they are readily taken up by biota such as mussels and finfish, and become associated with particulate material, which may ultimately be deposited to the sediment bed (McLean and Domotor 1988; Domotor and McLean 1989).

Table 5-7
Total quantities (Curies) of radionuclides released to the atmosphere by PBAPS via the main stack and roof vents: 1987-1988

Radionuclide	1987	1988
Tritium:	**29.64**	**7.04**
Noble Gases:		
Kr-85m	253.30	0.00
Kr-87	186.10	0.00
Kr-88	149.40	0.00
Xe-133	7,418.00	0.00
Xe-133m	129.90	0.00
Xe-135	1,357.00	0.00
Xe-135m	307.00	0.00
Xe-138	460.00	0.00
Total:	**10,260.70**	**0.00**
Iodines:		
I-131	0.01502	0.00000
I-133	0.01744	0.00000
I-135	0.00058	0.00000
Total:	**0.03304**	**0.00000**
Particulates:		
Cr-51	0.00016	0.00000
Co-57	0.00000	0.00005
Co-60	0.00037	0.00048
Zn-65	0.00037	0.00051
Sr-89	0.00252	0.00005
Sr-90	0.00005	0.00005
Sr-91	0.00166	0.00000
Y-91m	0.02804	0.00000
Mo-99	<0.00001	0.00000
Tc-99m	<0.00001	0.00000
Cd-109	<0.00001	0.00000
Te-132	0.00010	0.00000
Cs-137	0.00034	<0.00001
Cs-138	0.12970	0.00000
Ba-139	0.03003	0.00000
Ba-140	0.00085	0.00000
La-140	0.00131	0.00000
Total:	**0.19553**	**0.00115**
Total curies:	**10,290.57**	**7.04**

Source: PECO 1988b, 1989c.

Table 5-8
Total quantities (Curies) of radionuclides released to the Susquehanna River by PBAPS via the aqueous pathway: 1987-1988

Radionuclide	1987	1988
Tritium:	**46.37**	**9.69**
Dissolved Noble Gases:		
Xe-133	0.02416	0.00000
Xe-135	0.08294	0.00000
Xe-135m	0.00101	0.00000
Kr-85m	≤0.00001	0.00000
Total:	**0.10812**	**0.00000**
Iodines:		
I-131	0.00902	0.00000
I-133	0.00039	0.00000
I-134	0.00005	0.00000
Total:	**0.00946**	**0.00000**
Particulates:		
Na-24	0.00311	0.00000
Cr-51	0.01328	0.00000
Mn-54	0.00035	0.00004
Co-58	0.00220	0.00000
Co-60	0.03515	0.02886
Cu-64	0.04110	0.00000
Zn-65	0.10130	0.03468
Sr-89	0.00040	0.00027
Sr-90	0.00020	0.00057
Sr-92	0.00029	0.00000
Nb-95	0.00020	0.00000
Ag-110m	0.00252	0.00017
Cs-134	0.06058	0.04373
Cs-136	0.00043	0.00000
Cs-137	0.08157	0.07604
La-140	0.00022	0.00000
P-32	0.00348	0.00000
Fe-55	0.00473	0.01734
Total:	**0.35111**	**0.20170**
Total curies:	**46.84**	**9.89**

Source: PECO 1988b, 1989c.

Annual release totals for 1986 through 1988 of environmentally significant radionuclides that were subsequently detected in environmental media were the lowest reported since the beginning of PPER's monitoring effort in 1979 (Table 5-9). Consequently, concentrations of these radionuclides detected in biota and sediments were lower during 1986, and significantly lower or undetectable during 1987-1988, relative to previous years.

Environmental Monitoring Programs

PECO, MDE, and PPER conduct environmental surveillance programs in the vicinity of Peach Bottom Station to assess radiological impact attributable to plant operation. PECO's program focuses primarily on atmospheric and terrestrial impacts, but also includes aquatic monitoring of biota and sediments in the Conowingo Pond. MDE's program concentrates on the atmospheric pathway, and is designed to provide an independent confirmation of PECO's results, primarily through the weekly collection of air and raw milk samples. PPER's program is designed to provide information concerning environmental and health-related impacts of radioactivity released via the aqueous pathway. PPER seasonally collects aquatic biota and sediments from the Conowingo Pond, the lower Susquehanna River, and the Upper Chesapeake Bay. Detailed descriptions of individual environmental surveillance programs may be found elsewhere (DHMH 1988; PECO 1989b; Domotor and McLean 1990b).

Atmospheric and Terrestrial Radionuclide Distributions

No radioactivity attributable to atmospheric releases by Peach Bottom Station was detected in the terrestrial environment or atmosphere during 1987-1988 (PECO 1988a, 1989b; DHMH 1987, 1988). Gross alpha and beta concentrations were characteristic of background levels measured in previous years; concentrations at plant site and distant locations were similar. Low levels of Cs-137 sporadically detected in air, precipitation, raw milk, and crop samples from nearby and distant locations at similar concentrations are attributable to weapons test fallout; no plant-related increment of Cs-137 is discernible. Naturally occurring Be-7 was routinely detected in air particulate and precipitation samples throughout the reporting period. The very low quantities of radioactivity released did not contribute measurably to off-site radiation levels. A plant-related contribution to measured exposure rate (as determined by TLD) was not discernible (PECO 1988a, 1989b).

Aquatic Radionuclide Distributions

Concentrations of plant-related radionuclides detected in biota and sediments during the current reporting period were much lower than those observed prior to 1986, and reflect the significantly lower quantities of radionuclides discharged. Plant-related Zn-65, Cs-134, Cs-137, Co-58, and Co-60 were frequently detected in sediments and only occasionally detected in biota collected during 1987-1988 (PECO 1988a, 1989b; Domotor and McLean 1990b). The concentrations and distribution of Cs-137 (attributable to both Peach Bottom releases and weapons test fallout) in sediments and biota were similar to those reported in previous years.

Table 5-9
Annual aqueous release quantities (Curies) from PBAPS of radionuclides that have been detected in environmental media from the Susquehanna River-Chesapeake Bay system: 1979-1988

Release Year	Radionuclide				
	Cobalt-60	Zinc-65	Iodine-131	Cesium-134	Cesium-137
1979	0.16	0.46	0.96	3.92	3.26
1980	0.16	0.31	0.06	0.57	0.70
1981	0.13	0.29	0.05	0.10	0.17
1982	0.65	1.96	0.15	0.46	0.65
1983	0.16	0.79	0.13	0.15	0.26
1984	0.11	0.21	0.14	0.16	0.21
1985	0.14	0.23	0.12	0.22	0.23
1986	0.04	0.14	0.02	0.09	0.10
1987	0.02	0.06	0.002	0.06	0.05
1988	0.06	0.04	0.00	0.06	0.11

Source: PPRP 1988; PECO 1988b, 1989c.

Naturally occurring K-40 and radionuclides of the thorium and uranium decay series were detected in most biota and all sediments; Be-7 was also frequently detected, primarily in sediments. Maximum concentrations of Peach Bottom-related radionuclides detected in environmental media collected from the Susquehanna River-Chesapeake Bay system during 1987-1988 are presented in Table 5-10.

- Aquatic Biota

Finfish collected from Conowingo Pond, and from below the Pond at the Conowingo Dam tailrace, contained plant-related Zn-65, Cs-134, and Cs-137 (some fraction of Cs-137 is fallout-related). Low concentrations of Zn-65, Cs-134, and Cs-137 were detected in several edible finfish (including catfish, walleye, hybrid and smallmouth bass), primarily in 1987 (Domotor and McLean 1990b; PECO 1988a, 1989b). Zn-65 was detected in forage finfish (shiners) on one occasion. Co-60 was also detected at trace concentrations in catfish collected from the PBAPS discharge canal, primarily in 1987 (PECO 1988a, 1989b). Although not evident in the current reporting period, concentrations of plant-related radionuclides and their frequency of detection have generally been greater in finfish collected from the Conowingo Pond than in any other collection location since first monitored by PPER in 1979 (McLean *et al.* 1983; Domotor and McLean 1989). Finfish collected from the Holtwood Reservoir (six miles upstream of Peach Bottom) contained low concentrations of fallout-attributable Cs-137. Although not collected in 1987-1988, forage and edible finfish from the Susquehanna Flats (downstream) have contained low levels of plant-related radionuclides in previous years.

Low concentrations of Co-60, Zn-65, Cs-134, and Cs-137 were consistently detected in submerged aquatic vegetation (SAV) collected from the Conowingo Pond. SAV collected downstream -- from the Susquehanna Flats and Upper Chesapeake Bay -- contained only Cs-137, at reduced concentrations. SAV collected from the Susquehanna River and Susquehanna Flats have also consistently contained low levels of I-131. Medical facilities in the Harrisburg, Pennsylvania area (which discharge medical wastewater containing radioiodine into the river) are thought to be the primary source of I-131 detected in SAV. This is supported by the consistent detection of I-131 in SAV collected from the Swatara Creek (which is located upstream of both Peach Bottom and the Three Mile Island Nuclear Station) and subsequent downstream locations at comparable concentrations.

As was observed for finfish, plant-related Cs-134, Cs-137, and Zn-65 were only occasionally detected, at trace concentrations, in freshwater mussels and crayfish introduced and held in cages in the Conowingo Pond. Concentrations of all radionuclides were much lower than those observed prior to 1986, reflecting the significantly lower quantities of radionuclides released. Unlike previous reporting periods, no radiocobalt was detected in Conowingo Pond mussels or crayfish during 1987-1988. No radioactivity attributable to the plant or weapons test fallout was detected in crayfish or mussels from the Holtwood Reservoir, upstream of Peach Bottom Station.

Table 5-10

Maximum concentrations of radionuclides attributed to the Peach Bottom Atomic Power Station in environmental samples collected from the Susquehanna River and upper Chesapeake Bay: 1987-1988

			Radionuclide Concentration (pCi/wet kg)*			
Sample Type	Collection Location	Year	Cobalt-60	Cesium-134	Cesium-137	Zinc-65
Edible Finfish Flesh	Holtwood Reservoir	1987	<55	<54	6+-2	<118
		1988	<236	<189	14+-11	<693
	Conowingo Pond	1987	<119	2+-3	26+-29	<236
		1988	<80	6+-3	47+-36	<282
	Conowingo Dam Trailrace	1987	<33	7+-4	32+-6	<67
		1988	<9	<7	<8	<15
Edible Finfish Gut	Holtwood Reservoir	1987	<200	<351	<323	<250
		1988	<178	<147	<169	<441
	Conowingo Pond	1987	<411	<502	13+-14	<500
		1988	<243	<169	79+-63	49+-35
	Conowingo Dam Trailrace	1987	<349	<314	6+-3	4+-6
		1988	<78	<78	<88	<213
Forage Finfish (Whole)	Holtwood Reservoir	1987	<742	<685	<737	<500
		1988	<14	<68	8+-5	<27
	Conowingo Pond	1987	<59	<55	28+-19	78+-22
		1988	<18	<15	28+-16	<41
	Conowingo Dam Trailrace	1987	<10	<8	10+-3	<20
		1988	(not collected)			
Crayfish (Whole)	Holtwood Reservoir	1987	<186	<171	<202	<435
		1988	<107	<102	<121	<198
	Conowingo Pond	1987	<177	14+-6	37+-80	<346
		1988	<28	<24	28+-16	<50

Table 5-10 (continued)
Maximum concentrations of radionuclides attributed to the Peach Bottom Atomic Power Station in environmental samples collected from the Susquehanna River and upper Chesapeake Bay: 1987-1988

Sample Type	Collection Location	Year	Radionuclide Concentration (pCi/wet kg)* Cobalt-60	Cesium-134	Cesium-137	Zinc-65
Mussels (Flesh)	Holtwood Reservoir	1987	<33	<31	<33	<67
		1988	<36	<28	<32	<70
	Conowingo Pond	1987	<28	4+-3	6+-3	25+-7
		1988	<10	<10	<11	<25
	Susquehanna Flats	1987	<10	2+-3	<26	4+-5
		1988	<12	<9	<11	<25
Submerged Aquatic Vegetation (SAV)	Conowingo Pond	1987	14+-7	10+-5	24+-8	27+-16
		1988	32+-8	14+-5	39+-8	25+-12
	Susquehanna River	1987	<7	<7	12+-4	<14
		1988	<9	<7	11+-9	<17
	Upper Bay	1987	<17	<16	2+-9	<32
		1988	<12	<9	19+-6	<22
Sediment (Silt/Clay)	Holtwood Reservoir	1987	<14	<16	74+-11	<29
		1988	(no silt/clay sediments collected in 1988)			
	Conowingo Pond	1987	176+-13	178+-13	649+-24	125+-18
		1988	121+-35	110+-12	529+-12	63+-47
	Susquehanna Flats	1987	<22	33+-10	261+-18	<43
		1988	12+-8	15+-9	168+-24	<39
	Upper Bay	1987	18+-18	17+-7	231+-13	<145
		1988	<25	<18	188+-28	<50
Sediment (Sand)	Holtwood Reservoir	1987	<6	<6	71+-4	<13
		1988	<59	<48	139+-10	<121

Table 5-10 (continued)
Maximum concentrations of radionuclides attributed to the Peach Bottom Atomic Power Station in environmental samples collected from the Susquehanna River and upper Chesapeake Bay: 1987-1988

			Radionuclide Concentration (pCi/wet kg)*			
Sample Type	Collection Location	Year	Cobalt-60	Cesium-134	Cesium-137	Zinc-65
Sediment (Sand) (cont.)	Conowingo Pond	1987	<22	<31	54+-11	<50
		1988	76+-18	37+-13	348+-8	<32
	Susquehanna Flats	1987	<46	<42	65+-6	<112
		1988	<20	7+-4	162+-7	<44
	Upper Bay	1987	<2	<2	13+-2	<4
		1988	<2	<2	13+-2	<4

Source: Domotor and McLean 1990b
* Sediment radionuclide concentrations are in pCi/dry kg units.

- Sediments

Heavy metal radionuclides (e.g., radiocobalt and radiocesium) contained in the plant's liquid effluent are generally very particle-reactive, rapidly becoming associated with particulate material suspended in the water column. This particle-bound radioactivity may ultimately become deposited on the river bottom, or be transported downriver and down-bay as particulates or resuspended sediments. Results from PPER's semi-annual sediment collections provide an indication of the accumulation, transport, and relocation of particle-bound radioactivity in the Susquehanna River-Chesapeake Bay system over time.

As with biota, plant-related radionuclide concentrations in sediments collected from all locations were lower than levels observed prior to 1986. As in previous years, Co-60, Zn-65, Cs-134, and Cs-137 (some fraction of Cs-137 is fallout-attributable) were detected in sediments collected during 1987-1988. Concentrations of all radionuclides were generally highest along the western shore of the Conowingo Pond, downstream of the plant discharge. Reduced concentrations of these radionuclides were also detected in sediments collected from the Susquehanna Flats and Upper Bay, indicating that particle-bound radioactivity originating from Peach Bottom Station is transported downstream of the Conowingo Pond. Particle dilution, dispersion, and radioactive decay during transport (or during residence in the Conowingo Pond) cause concentrations to diminish with distance downriver.

Mass balance (the ratio of radionuclide concentrations detected in sediments to the total released) estimates indicate that less than 20 percent of the plant-related Co-60, Cs-134, Cs-137, and Zn-65 released is found in surface sediments of the Conowingo Pond (McLean *et al.* 1988). Deep core samples (about 200 cm depth) confirm that some, but not all, of this surface sediment radionuclide inventory remains within the reservoir, trapped in discrete locations by subsequent sediment accumulation. The remaining radionuclide mass in dissolved or particle-associated forms appears to be transported downstream, through the Conowingo Dam, to the Chesapeake Bay. With the exception of some Cs-137 attributable to weapons test fallout, no plant-related radionuclides were detected in the Holtwood Reservoir, upstream of Peach Bottom.

Radiation Dose to Humans

Estimates of dose commitments to individuals consuming finfish were calculated using the maximum plant-related radionuclide concentrations (for Zn-65, Cs-134, and Cs-137) detected in finfish flesh as determined by PPER during 1987-1988. Estimated dose commitments to adults, teenagers, and children are presented in Table 5-11. The estimated maximum dose from finfish consumption would be about 0.13 mrem to a teenager's liver. The estimated maximum total body dose would be about 0.09 mrem to an adult.

The Susquehanna River is a source of drinking water, which may potentially contribute to a human radiation dose. The annual total body dose associated with consumption of drinking water containing tritium, radiocesium, and Zn-65 in the

Table 5-11
Maximum estimated dose commitments* (in mrem) for an individual consuming finfish affected by PBAPS releases

	ADULT		TEEN		CHILD	
	1987	1988	1987	1988	1987	1988
Total Body						
Zn-65	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Cs-134	0.0178	0.0152	0.0102	0.0088	0.0039	0.0034
Cs-137	0.0480	0.0705	0.0266	0.0390	0.0102	0.0150
TOTAL:	**0.0658**	**0.0857**	**0.0368**	**0.0478**	**0.0141**	**0.0184**
Bone						
Zn-65	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Cs-134	0.0091	0.0078	0.0094	0.0080	0.0113	0.0097
Cs-137	0.0535	0.0787	0.0573	0.0842	0.0722	0.1060
TOTAL:	**0.0626**	**0.0865**	**0.0667**	**0.0922**	**0.0835**	**0.1157**
Liver						
Zn-65	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Cs-134	0.0218	0.0186	0.0221	0.0190	0.0185	0.0159
Cs-137	0.0732	0.1076	0.0763	0.1120	0.0691	0.1015
TOTAL:	**0.0950**	**0.1262**	**0.0984**	**0.1310**	**0.0876**	**0.1174**
Kidney						
Zn-65	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Cs-134	0.0070	0.0060	0.0070	0.0060	0.0057	0.0049
Cs-137	0.0249	0.0365	0.0260	0.0381	0.0225	0.0331
TOTAL:	**0.0319**	**0.0425**	**0.0330**	**0.0441**	**0.0282**	**0.0380**
GI Tract						
Zn-65	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000 -
Cs-134	0.0004	0.0003	0.0003	0.0002	0.0001	0.0001
Cs-137	0.0014	0.0021	0.0011	0.0016	0.0004	0.0006
TOTAL:	**0.0018**	**0.0024**	**0.0014**	**0.0018**	**0.0005**	**0.0007**

(*) Based upon maximum radionuclide concentrations given in Table 5-12. Recommended consumption values and dose factors used in calculations are from the USNRC Regulatory Guide 1.109.

quantities released (Table 5-8), assuming an average river flow of 36,000 cfs, is estimated to be less than 0.004 mrem. This is a very conservative estimate, because treating the water for drinking purposes would remove almost all of the cesium and zinc.

Estimated doses to individuals through the consumption of river water and finfish for 1987-1988 are less than those calculated for previous reporting periods. For comparison, the highest total body dose estimated in the past was just over 1 mrem, for the 1978-1980 period. These estimates are well within 10 CFR Part 50 Appendix I regulatory guidelines of 6 mrem/yr.

Summary

No Peach Bottom-related radionuclides attributable to atmospheric releases were detected in the terrestrial environment or atmosphere during 1987-1988. Plant-related radionuclides attributable to aqueous releases to the Susquehanna River produced low levels of Co-60, Zn-65, Cs-134, and Cs-137 in aquatic biota (including edible finfish and SAV) and sediments collected from the Conowingo Pond. These radionuclides were also detected in sediments collected downstream of Peach bottom -- from the Susquehanna Flats and upper Chesapeake Bay -- at reduced concentrations. Plant-related radionuclide concentrations in biota and sediments were much lower than those observed in previous years, reflecting the lower quantities of radionuclides released due to the shutdown of Peach Bottom Station in early 1987.

Results of radiological monitoring conducted by PPER from 1979 to 1988 indicate that there is no accumulation or build-up of radioactivity within the Conowingo Pond resulting from the long-term operation of Peach Bottom Station. The low concentrations of plant-related radionuclides in biota and sediments represent small increments to the Susquehanna River-Chesapeake Bay system relative to natural and weapons test levels. Atmospheric and aqueous releases by PBAPS, and radiation doses to humans, are well within regulatory limits.

D. Radioactive Waste Disposal

The operation of a nuclear power plant produces two types of radioactive waste requiring off-site disposal: low-level waste and spent fuel. Low-level waste (LLW), characterized by relatively low concentrations of radionuclides, includes such items as spent decontamination resins, filter sludges, contaminated equipment, and protective clothing. Spent fuel is reactor fuel that has completed its useful life.

Total volumes and radioactivity levels of LLW shipped from Calvert Cliffs and Peach Bottom in 1987 and 1988 are presented in Table 5-12. Of the 84,871 cubic feet of waste shipped from Peach Bottom, approximately 8,500 ft^3 is attributable to the March 1987 replacement of Unit 3 recirculation piping. All LLW generated at the two plants was shipped to either Barnwell, South Carolina or Hanford, Washington.

Table 5-12
Low-level solid waste (LLW) shipped off-site for disposal by CCNPP and PBAPS during 1987 and 1988

Plant	Year	Volume (Cu Ft.)	Activity (Ci)	No. of Shipments
CCNPP	1987	8,478	755	11
	1988	8,577	1,127	13
	Total:	**17,055**	**1,882**	**24**
PBAPS	1987	55,774	3,888	315
	1988	29,097	1,188	162
	Total:	**84,871**	**5,076**	**477**

Source: BG&E 1988b, 1989c; PECO 1988b, 1989c

Spent nuclear fuel from Calvert Cliffs and Peach Bottom is currently stored in spent fuel pools at each site. While capacity for pool storage is not, in the near future, limited at Peach Bottom, it is projected that Calvert Cliffs' existing pool storage capacity will be exhausted by the mid-1990s. Because an interim federal repository for spent commercial nuclear fuel is not expected to be available until at least 1998, and a permanent disposal site not available until the year 2010, BG&E has reracked fuel assemblies to maximize existing on-site water pool storage capacity, and has developed a plan to construct and operate an independent spent fuel storage installation (ISFSI) on site.

BG&E's proposal for an ISFSI was submitted to USNRC in December 1989, and is currently under review by USNRC and the State. The application requests a license to construct and operate an ISFSI of 120 modules (2,880 fuel assemblies) to be built incrementally to match the plant's requirements for storage. It is expected that operation of the facility will continue for up to 20 years under the initial license and later under license renewal as necessary until a permanent off-site repository is available. Given final license approval, phase one preoperational testing is anticipated to begin in February 1992, and initial operation in 1993.

E. References

BG&E (Baltimore Gas and Electric Company) 1988a. Radiological environmental monitoring program annual report for the Calvert Cliffs Nuclear Power Plant Units 1 and 2; January 1 - December 31, 1987.

BG&E. 1988b. Semi-annual effluent release reports for Calvert Cliffs Nuclear Power Plant, January 1 - December 31, 1987.

BG&E. 1989a. Calvert Cliffs monthly operating report for December, 1988.

BG&E. 1989b. Radiological environmental monitoring program annual report for the Calvert Cliffs Nuclear Power Plant Units 1 and 2; January 1 - December 31, 1988.

BG&E. 1989c. Semi-annual effluent release reports for Calvert Cliffs Nuclear Power Plant, January 1 - December 31, 1988.

DHMH (Maryland Department of Health and Mental Hygiene). 1987. Quarterly environmental radiological monitoring reports.

DHMH. 1988. Quarterly environmental radiological monitoring reports.

Domotor, S. L. and R. I. McLean. 1987. Environmental radionuclide concentrations in the vicinity of the Calvert Cliffs Nuclear Power Station: 1981-1984. Prepared by the Maryland Department of Natural Resources, Power Plant Research Program, Annapolis, MD. PPRP-R-8.

Domotor, S. L. and R. I. McLean. 1988. Environmental radionuclide concentrations in the vicinity of the Calvert Cliffs Nuclear Power Station: 1985-1986. Prepared by the Maryland Department of Natural Resources, Power Plant Research Program, Annapolis, MD. PPRP-R-10.

Domotor, S. L. and R. I. McLean. 1989. Environmental radionuclide concentrations in the vicinity of the Peach Bottom Atomic Power Station: 1985-1986. Prepared by the Maryland Department of Natural Resources, Power Plant and Environmental Review Division, Annapolis, MD. PPER-R-11.

Domotor, S. L. and R. I. McLean. 1990a. Environmental radionuclide concentrations in the vicinity of the Calvert Cliffs Nuclear Power Plant: 1987-1988. Prepared by the Maryland Department of Natural Resources, Power Plant and Environmental Review Division, Annapolis, MD. (In prep.)

Domotor, S. L. and R. I. McLean. 1990b. Environmental radionuclide concentrations in the vicinity of the Peach Bottom Atomic Power Station: 1987-1988. Prepared by the Maryland Department of Natural Resources, Power Plant and Environmental Review Division, Annapolis, MD. (In prep.)

Eisenbud, M. 1987. Environmental Radioactivity from Natural, Industrial, and Military Sources. Third edition. Orlando, FL: Academic Press, Inc.

GPUN (General Public Utility Nuclear Corporation, Three Mile Island Group). 1989. Radiological environmental monitoring report for Three Mile Island Nuclear Power Station: 1988.

McLean, R. I., T. E. Magette, and S. G. Zobel. 1982. Environmental radionuclide concentrations in the vicinity of the Calvert Cliffs Nuclear Power Plant: 1978-1980. Prepared by the Maryland Department of Natural Resources, Power Plant Research Program, Annapolis, MD. PPRP-R-4.

McLean, R. I. and S. L. Domotor. 1988. Environmental radionuclide concentrations in the vicinity of the Peach Bottom Atomic Power Station: 1981-1984. Prepared by the Maryland Department of Natural Resources, Power Plant Research Program, Annapolis, MD. PPRP-R-9.

McLean, R. I., J. K. Summers, S. L. Domotor, C. R. Olson and V. A. Dickens. 1988. Radionuclide concentrations in Susquehanna River and Chesapeake Bay sediments - implications for transport and distribution of particle-reactive pollutants. In: Understanding the Estuary: Advances in Chesapeake Bay Research. Chesapeake Bay Research Consortium, March 29-31, 1988, Gloucester Point, VA.

NCRPM (National Council on Radiation Protection and Measurements). 1988. Ionizing radiation exposures of the population of the United States. Bethesda, MD: NCRPM.

USNRC (United States Nuclear Regulatory Commission). 1977. Calculation of annual doses to man from routine releases of reactor effluents for the purpose of evaluating compliance with 10 CFR Part 50, Appendix I. Reg. Guide 1.109. U.S. Government Printing Office, Washington, D.C.

PECO (Philadelphia Electric Company). 1988a. Peach Bottom Atomic Power Station annual radiological environmental operating report No. 45, 1 January 1987 - 31 December 1987.

PECO 1988b. Semi-annual effluent release reports for the Peach Bottom Atomic Power Station, Units 2 and 3, January 1 - December 31, 1987.

PECO 1989a. Peach Bottom Atomic Power Station monthly operating report for December, 1988.

PECO 1989b. Peach Bottom Atomic Power Station annual radiological environmental operating report No. 46, 1 January 1988 - 31 December 1988.

PECO 1989c. Semi-annual Effluent Reports for the Peach Bottom Atomic Power Station, Units 2 and 3, January 1 - December 31, 1988.

PPRP (Maryland Department of Natural Resources Power Plant Research Program). 1988. Power plant cumulative environmental impact report for Maryland. Prepared by the Maryland Department of Natural Resources, Power Plant Research Program, Annapolis, MD. PPRP-CEIR-6.

Rose, K.A., J.K. Summers, R.I. McLean and S.L. Domotor. 1988. Radiosilver (Ag-110m) concentrations in Chesapeake Bay oysters maintained near a nuclear power plant: a statistical analysis. Jour. Environ. Monit. and Assessment 10:205-218.

Rose, K.A., R.I. McLean and J.K. Summers. 1989. Development and Monte Carlo analysis of an oyster bioaccumulation model applied to biomonitoring data. Ecological Modelling 45:111-132.

F. Glossary

Alara. Used to describe an approach to radiation exposure control or management whereby the exposures and resulting doses are maintained as far below the limits specified for the appropriate circumstances as social, economic, technical, and practical considerations merit (literally, As Low As Reasonably Achievable).

Biota. The animal and plant life of a particular region considered as a total ecological entity.

Concentration. The amount of a substance contained in a unit volume or mass of sample.

Cosmic radiation. High energy particulate and electromagnetic radiation originating outside the earth's atmosphere. Cosmic radiation is one source contributing to natural background radiation.

Curie (Ci). A unit of radioactivity. One curie is defined as 3.7×10^{10} (37 billion) disintegrations per second. Several fractions of the curie are commonly used for quantifying levels of radioactivity in the environment. These are the millicurie (mCi), -10^{-6} Ci, and the picocurie (pCi), -10^{-12} Ci.

Dose. The energy imparted to matter by ionizing radiation. The unit of absorbed dose is the rad, equal to 0.01 joules per kilogram for irradiated material in any medium.

Dose commitment. The dose that an organ or tissue would receive during a specified period of time (e.g., a 50-year period is used in dose calculations in this report) as a result of intake (as by ingestion or inhalation) of one or more radionuclides from one year's release.

Effective dose equivalent. An estimate of the total risk of potential health effects from radiation exposure. It is the sum of the committed effective dose equivalent from internal deposition and the effective dose equivalent from external penetrating radiation received during a calendar year.

Effluent. A liquid or gaseous waste discharged to the environment.

Environmentally significant. As used in this report, refers to radionuclides that are known to be assimilated by biological organisms, and are discharged in detectable amounts. Not included are aqueous releases of noble gases, tritium, or very short-lived radionuclides.

Environmental surveillance. The collection and analysis of samples of air, water, soil, foodstuffs, biota, and other media to determine environmental quality. It is commonly performed at sites containing nuclear facilities.

External radiation. Exposure to ionizing radiation when the radiation source is located outside of the body.

Half-life. The time required for a radioactive substance to lose one-half of its activity by decay. Each radionuclide has a unique half-life.

Ionizing radiation. Any electromagnetic or particulate radiation capable of producing ions (electrically charged atoms or atomic particles), directly or indirectly, in its passage through matter.

Maximally exposed individual. A hypothetical individual who remains in an uncontrolled area and would, when all potential routes of exposure from a facility's operations are considered, receive the greatest possible dose.

Minimum detectable concentration (MDC). The smallest amount or concentration of a radionuclide that can be distinguished in a sample with a given degree of confidence (usually 95 percent). The MDC is affected by the counting efficiency, gamma-ray detector used, and amount of other radiation present.

Mrem. The dose equivalent that is one-thousandth of a rem.

Natural radiation. Radiation attributable to cosmic and other naturally occurring radionuclides present in the environment.

Noble gases. A group of elements that have an extremely limited ability to react chemically. Also known as inert gases, they include helium, neon, argon, krypton, xenon, and radon.

Outfall. The end of a drain or pipe carrying effluent into a river, pond, or bay.

Radioactivity. The spontaneous emission of radiation, generally alpha or beta particles, or gamma rays, from the nucleus of an unstable isotope.

Radioactive decay. The spontaneous transformation of one nuclide into a different radioactive or nonradioactive nuclide, or into a different energy state of the same nuclide.

Radionuclide. An unstable nuclide capable of spontaneous transformation into other nuclides by changing its nuclear configuration or energy level. This transformation is accompanied by the emission of photons or particles.

Rem. The unit dose equivalent (rad multiplied by a quality factor). Dose equivalent is frequently reported in units of millirem (mrem), which is one-thousandth of a rem.

Stable. Not radioactive or not easily decomposed or otherwise modified chemically.

Substrate. The substance, base, surface, or medium in or on which an organism lives and grows.

Thermoluminescence dosimetry (TLD). A technique used to measure external gamma radiation levels in the environment.

Weapons test fallout. Radioactive debris from atmospheric weapons tests that has been distributed and deposited on the earth's surface after being airborne.